DEQ’s Approach to Developing Numeric Nutrient Standards for Wadeable Streams and Rivers

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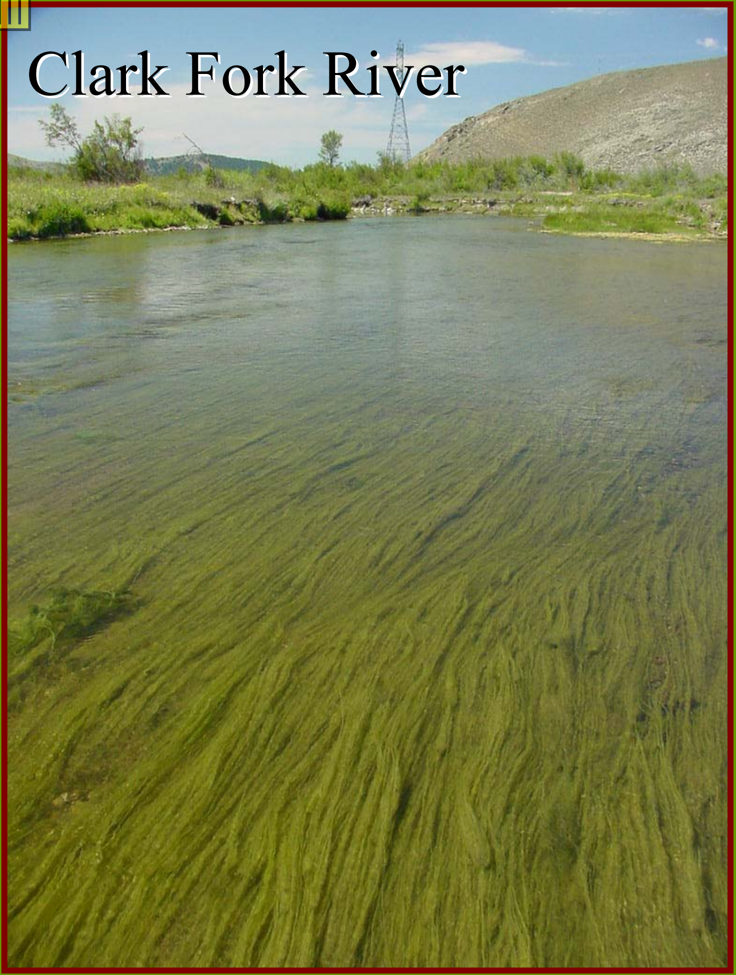
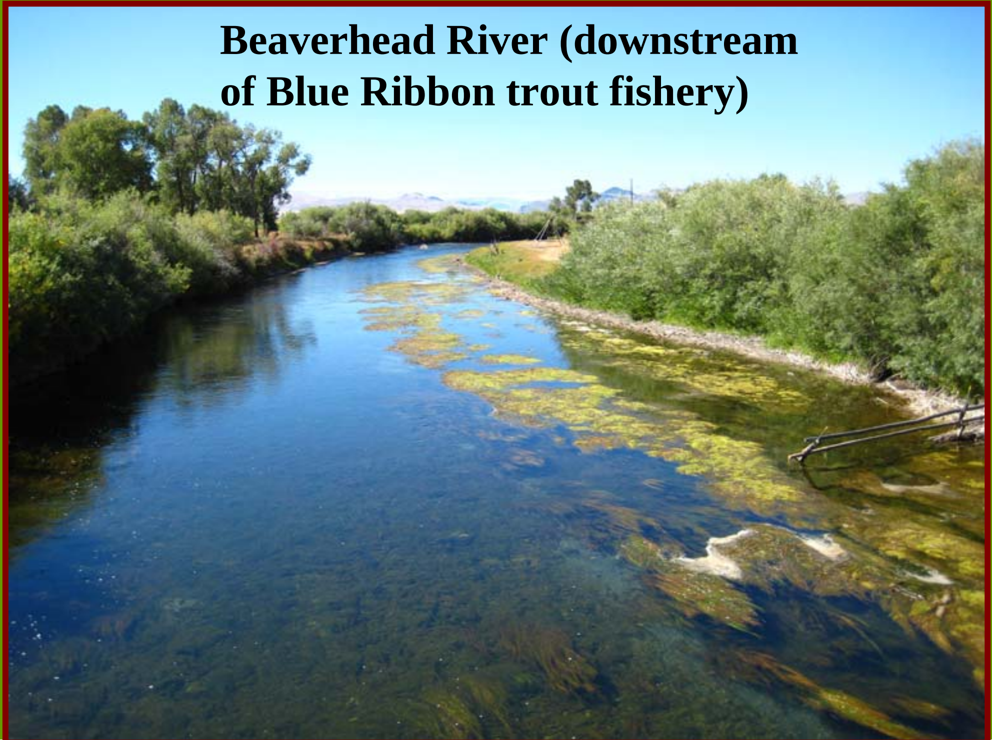
Presentation for Nutrient Work Group (meeting 3)

July 16, 2009

Outline

- Review of various benthic algae levels found in temperate wadeable streams (Montana, world)
- 150 mg Chl*a*/m^2 benthic algae in relation to stream ecological changes and beneficial uses (gravel bottom salmonid streams)
- Linkage between DO and nutrients in prairie streams
- Criteria derivation
- Work from other states

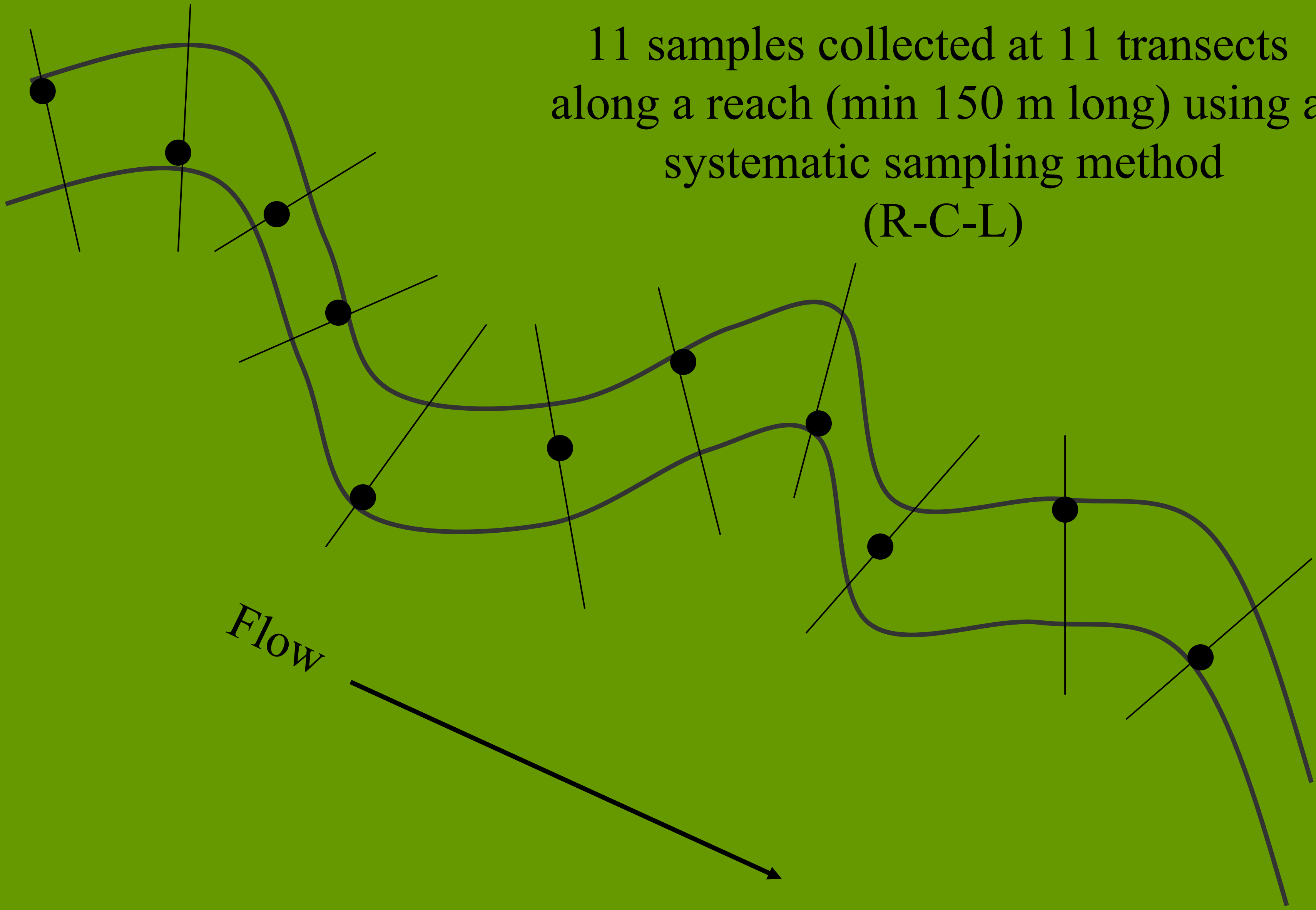




Nuisance algal growth

Sampling Benthic Algae

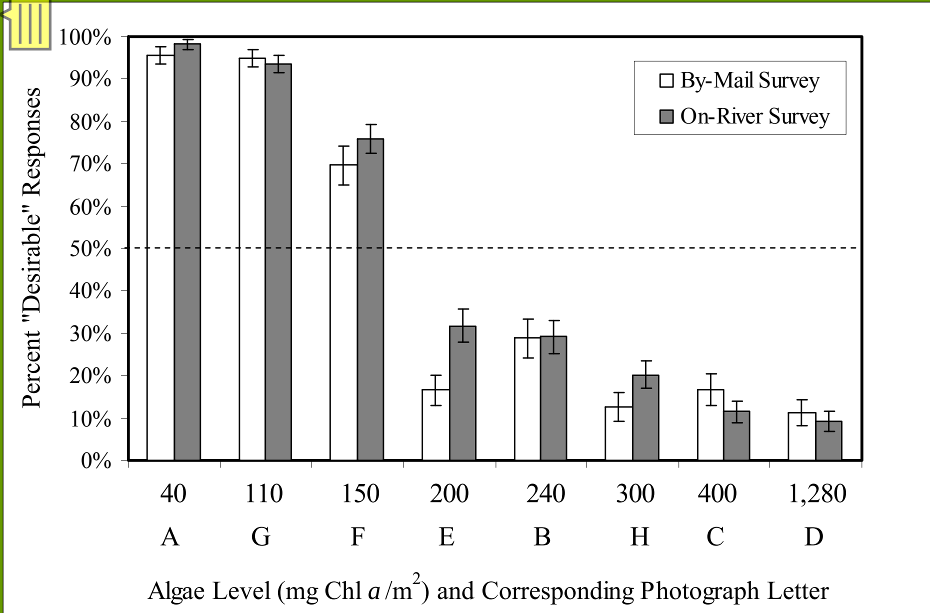
11 samples collected at 11 transects along a reach (min 150 m long) using a systematic sampling method (R-C-L)



Duplicate benthic algae Chl *a* measurements (reach mean) are consistent, with a coefficient of variation of ca. 20%

Beaver Creek	***M09BEVRC05***	***Units***	DL	
Chlorophyll a, corrected for pheophytin	65.5	mg/m2	0.01	mg/m2
Chlorophyll a, corrected for pheophytin	60	mg/m2	0.01	mg/m2
Chlorophyll a, corrected for pheophytin	29.3	mg/m2	0.01	mg/m2
Chlorophyll a, corrected for pheophytin	30.5	mg/m2	0.01	mg/m2
Chlorophyll a, corrected for pheophytin	22.7	mg/m2	0.01	mg/m2
Chlorophyll a, corrected for pheophytin	14.9	mg/m2	0.01	mg/m2
Chlorophyll a, corrected for pheophytin	52.9	mg/m2	0.01	mg/m2
Chlorophyll a, corrected for pheophytin	34.4	mg/m2	0.01	mg/m2
Chlorophyll a, corrected for pheophytin	16.3	mg/m2	0.01	mg/m2
Chlorophyll a, corrected for pheophytin	39.6	mg/m2	0.01	mg/m2
Chlorophyll a, corrected for pheophytin	195	mg/m2	0.01	mg/m2
Average:	**51.0**			

Beaver Creek (Duplicate)	***M09BEVRC05***			
Chlorophyll a, corrected for pheophytin	88.3	mg/m2	0.01	mg/m2
Chlorophyll a, corrected for pheophytin	35	mg/m2	0.01	mg/m2
Chlorophyll a, corrected for pheophytin	13.3	mg/m2	0.01	mg/m2
Chlorophyll a, corrected for pheophytin	63.6	mg/m2	0.01	mg/m2
Chlorophyll a, corrected for pheophytin	70.7	mg/m2	0.01	mg/m2
Chlorophyll a, corrected for pheophytin	78.9	mg/m2	0.01	mg/m2
Chlorophyll a, corrected for pheophytin	59.4	mg/m2	0.01	mg/m2
Chlorophyll a, corrected for pheophytin	110	mg/m2	0.01	mg/m2
Chlorophyll a, corrected for pheophytin	39.4	mg/m2	0.01	mg/m2
Chlorophyll a, corrected for pheophytin	153	mg/m2	0.01	mg/m2
Chlorophyll a, corrected for pheophytin	24.5	mg/m2	0.01	mg/m2
Average:	**66.9**			

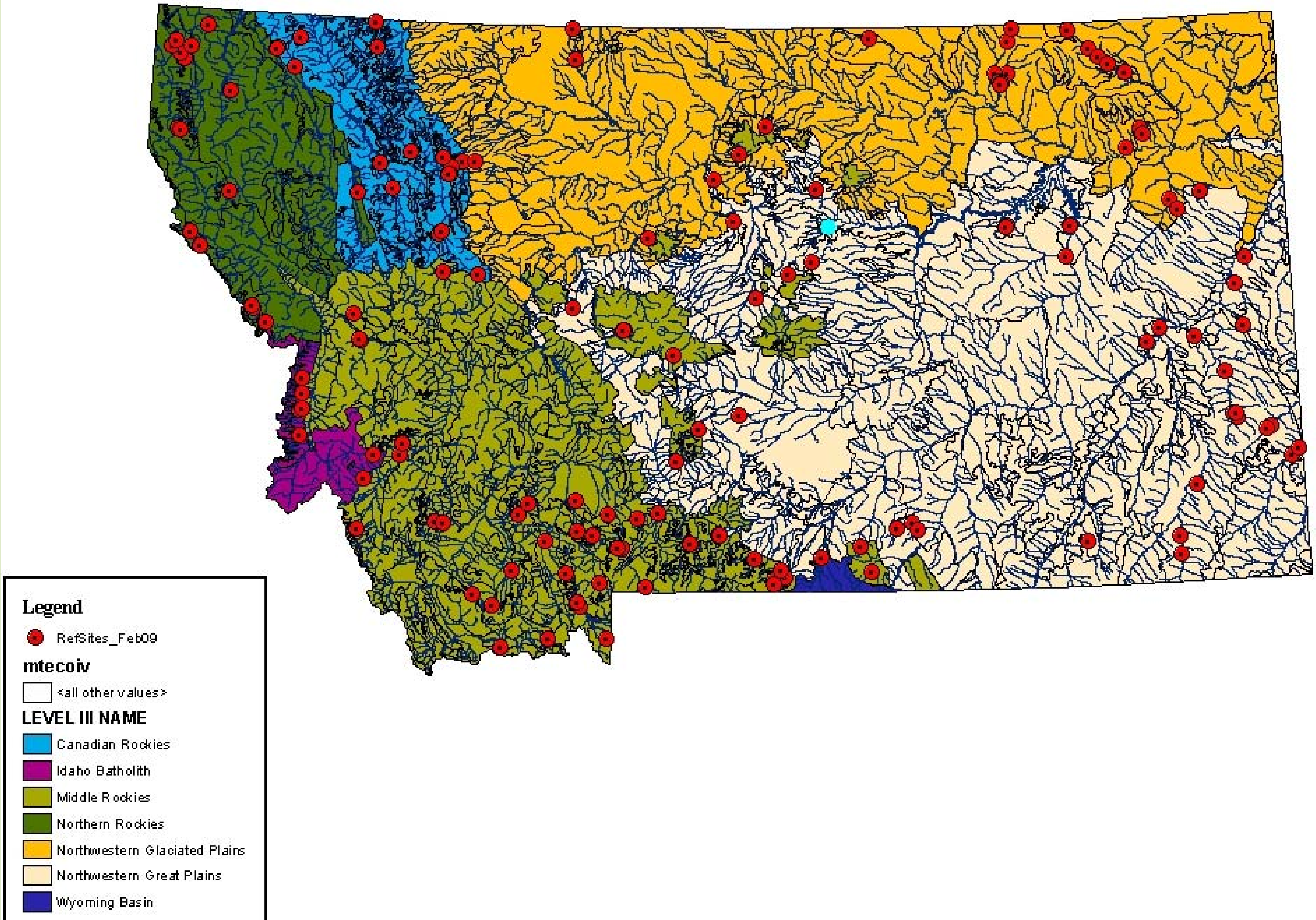


Harm to Use: Recreation Threshold

Suplee, Watson, Teply & McKee, 2009. How Green is too Green? Public Opinion of what Constitutes Undesirable Algae Levels in Streams. *Journal of the American Water Resources Association* **43**: 123-140.

Where does 150 mg Chl *a*/m^2 benthic algae fit into the larger picture?

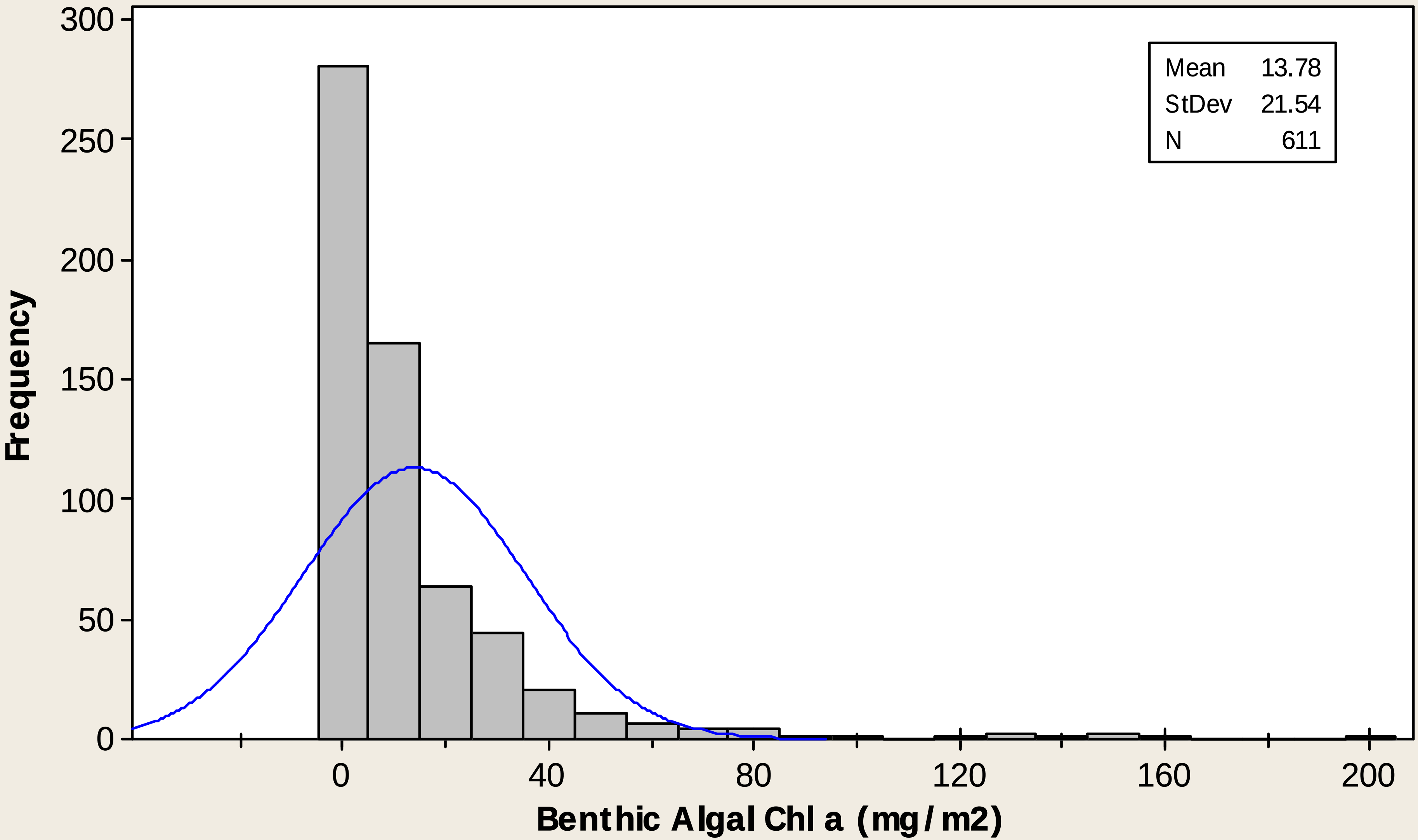
- Compared to reference stream data
  - Western Montana
  - Eastern Montana
- Compared to temperate streams worldwide
- What stream ecological conditions are found below and above 150 mg Chl*a*/m^2?



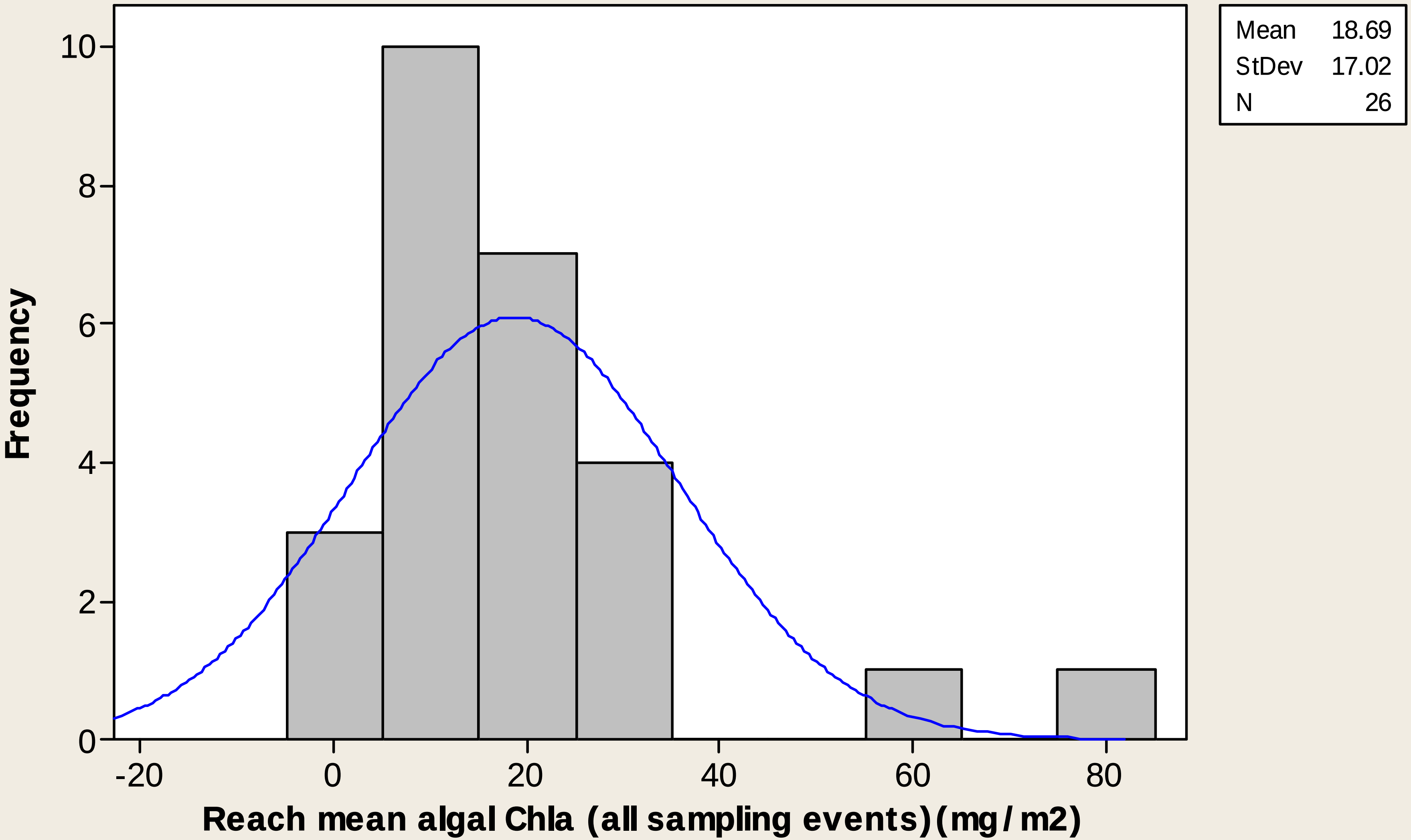
Legend
RefSites_Feb09
mtecoiv
<all other values>
LEVEL III NAME
Canadian Rockies
Idaho Batholith
Middle Rockies
Northern Rockies
Northwestern Glaciated Plains
Northwestern Great Plains
Wyoming Basin

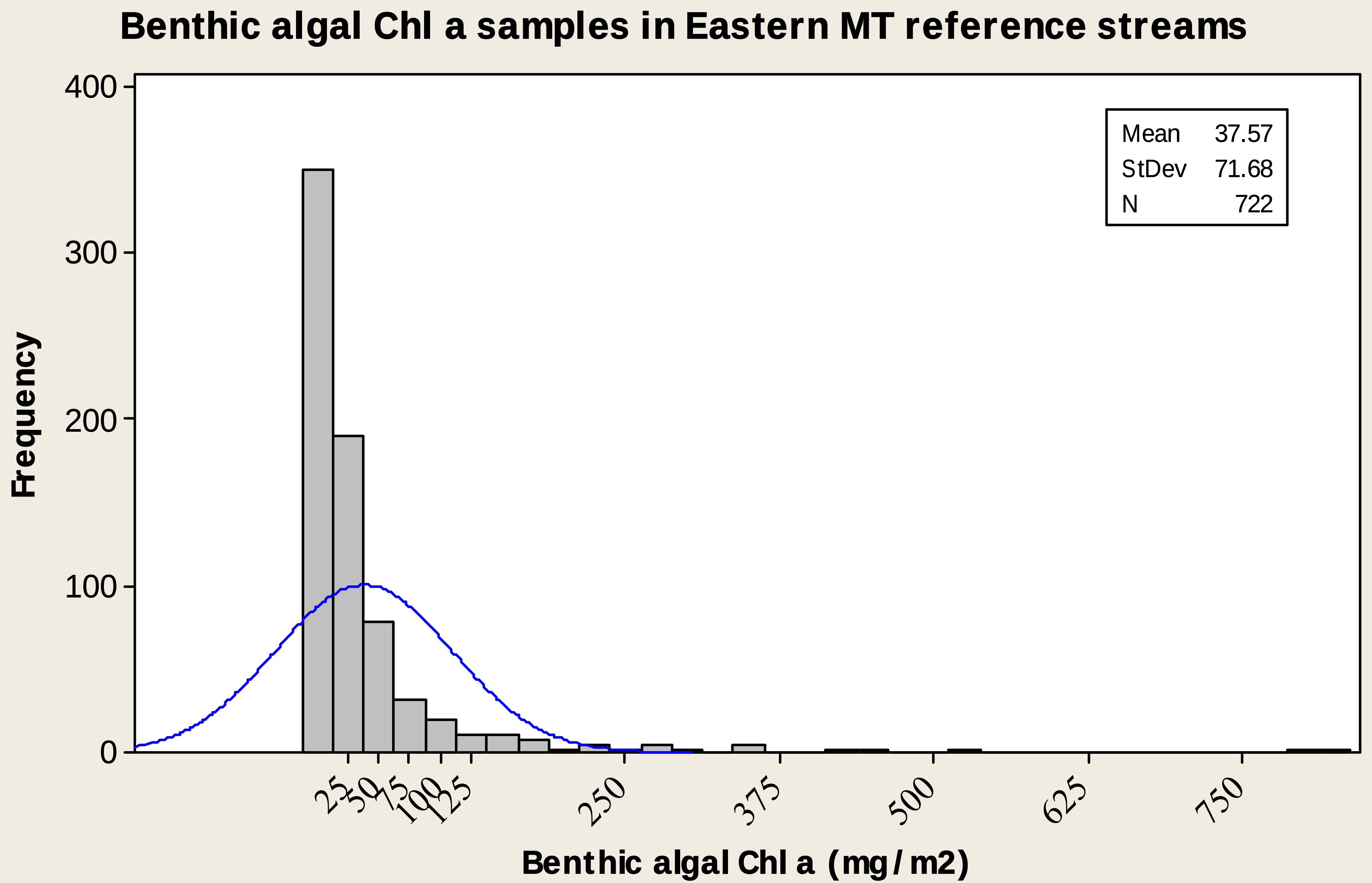
DEQ’s network of reference stream sites provide benthic algae, nutrient, biometric, and other data

Benthic algal Chl a samples in western MT reference streams (2001-2008)



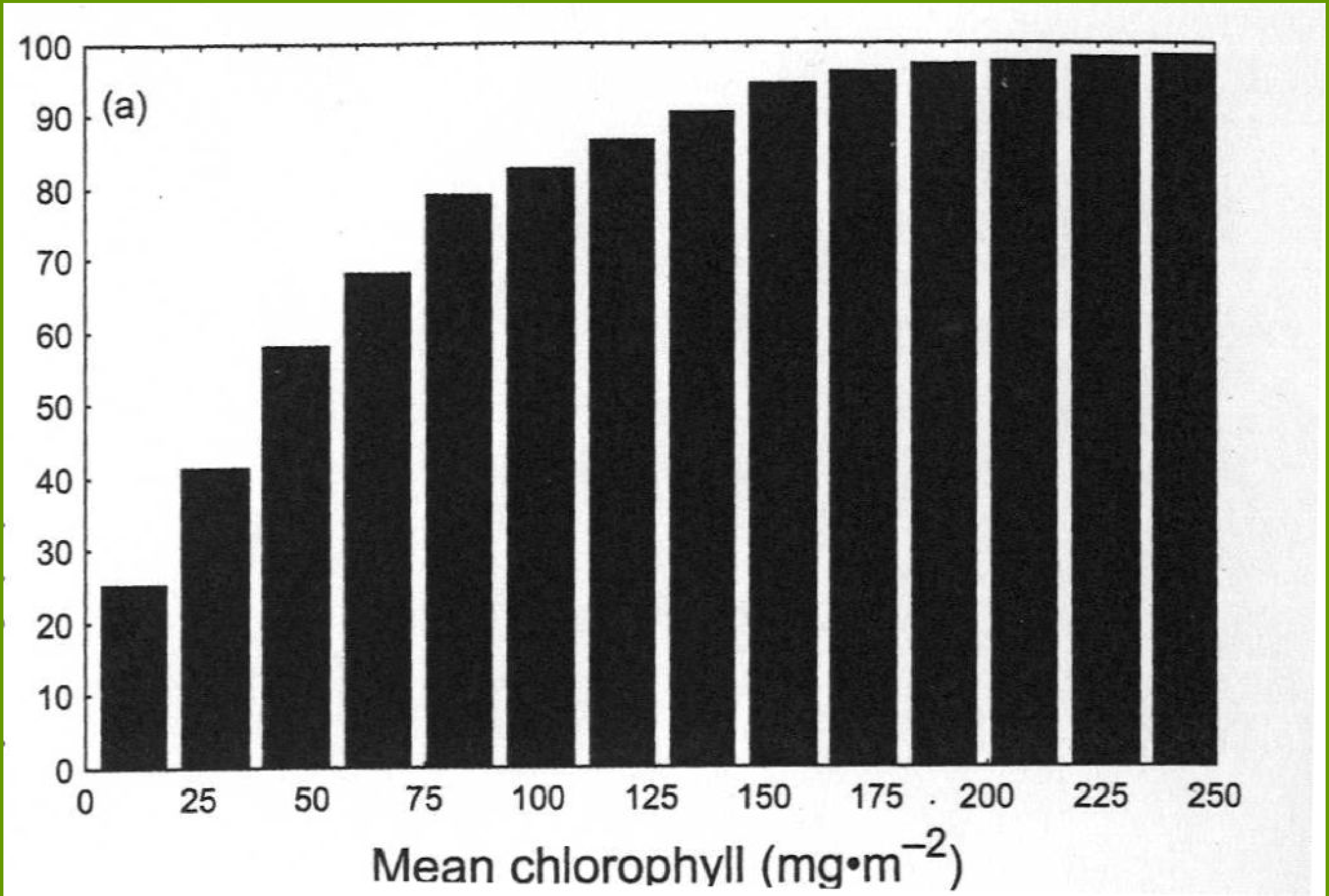
Mean reach benthic algal Chl a in western MT reference streams (01-08)





Benthic algal Chl a samples in Eastern MT reference streams
400
300
200
100
0
Frequency
Mean 37.57
StDev 71.68
N 722
25
50
75
100
125
250
375
500
625
750
Benthic algal Chl a (mg/m2)

Benthic algae in temperate streams worldwide
(n = 246 different streams)



Dodds, W.K., Smith, V.H., and K. Lohman, 2002. Nitrogen and phosphorus relationships to benthic algal Biomass in temperate streams. Can. J. Fish. Aquat. Sci. 59: 865-874.

Key Points Summary

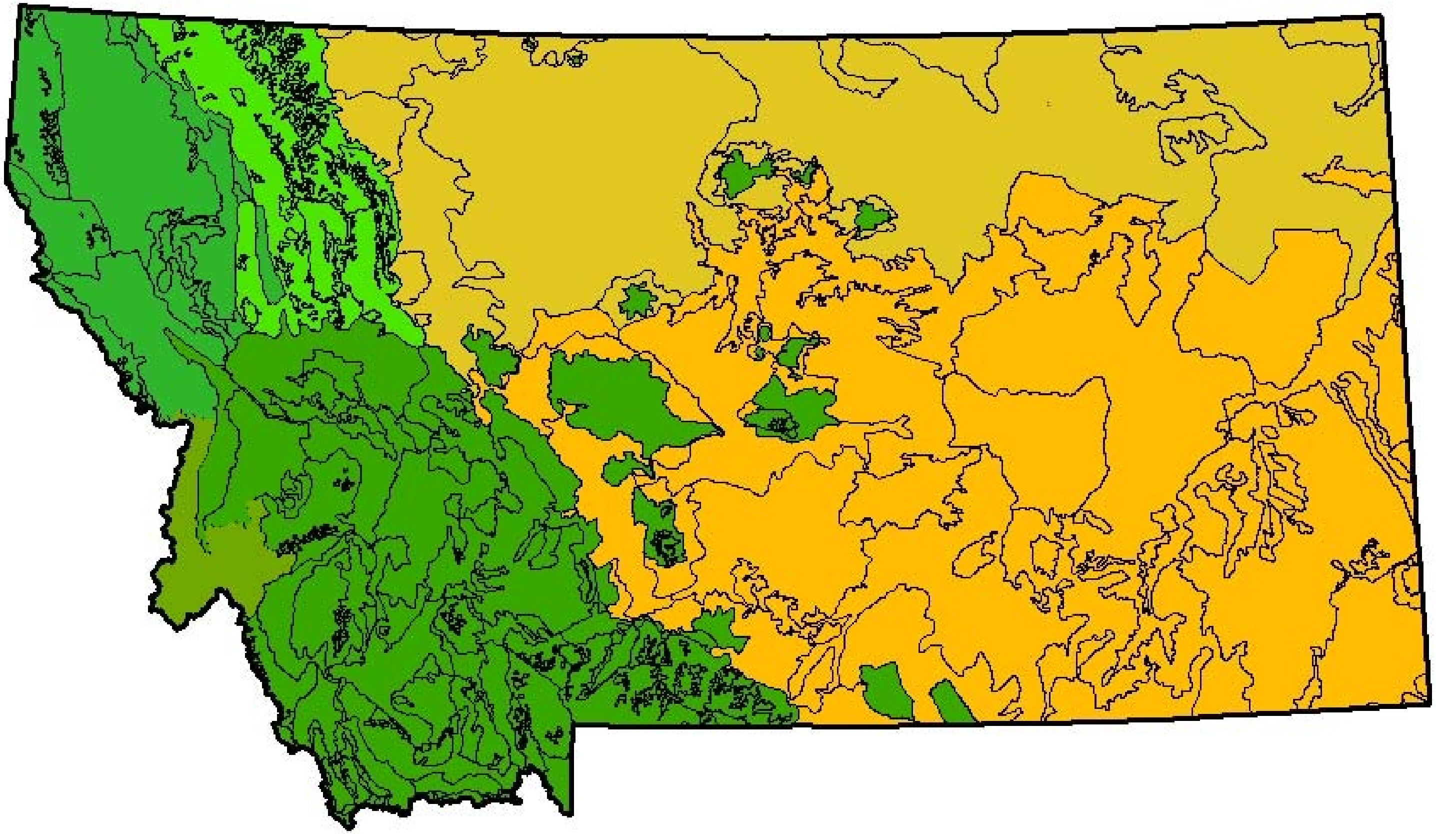
- 150 mg Chl*a*/m^2 is viewed as a nuisance threshold by the Montana public

- 150 mg Chl*a*/m^2 rarely occurs in individual samples from western MT reference streams, and never occurs as a reach average
  - Somewhat more common in E. MT prairie streams

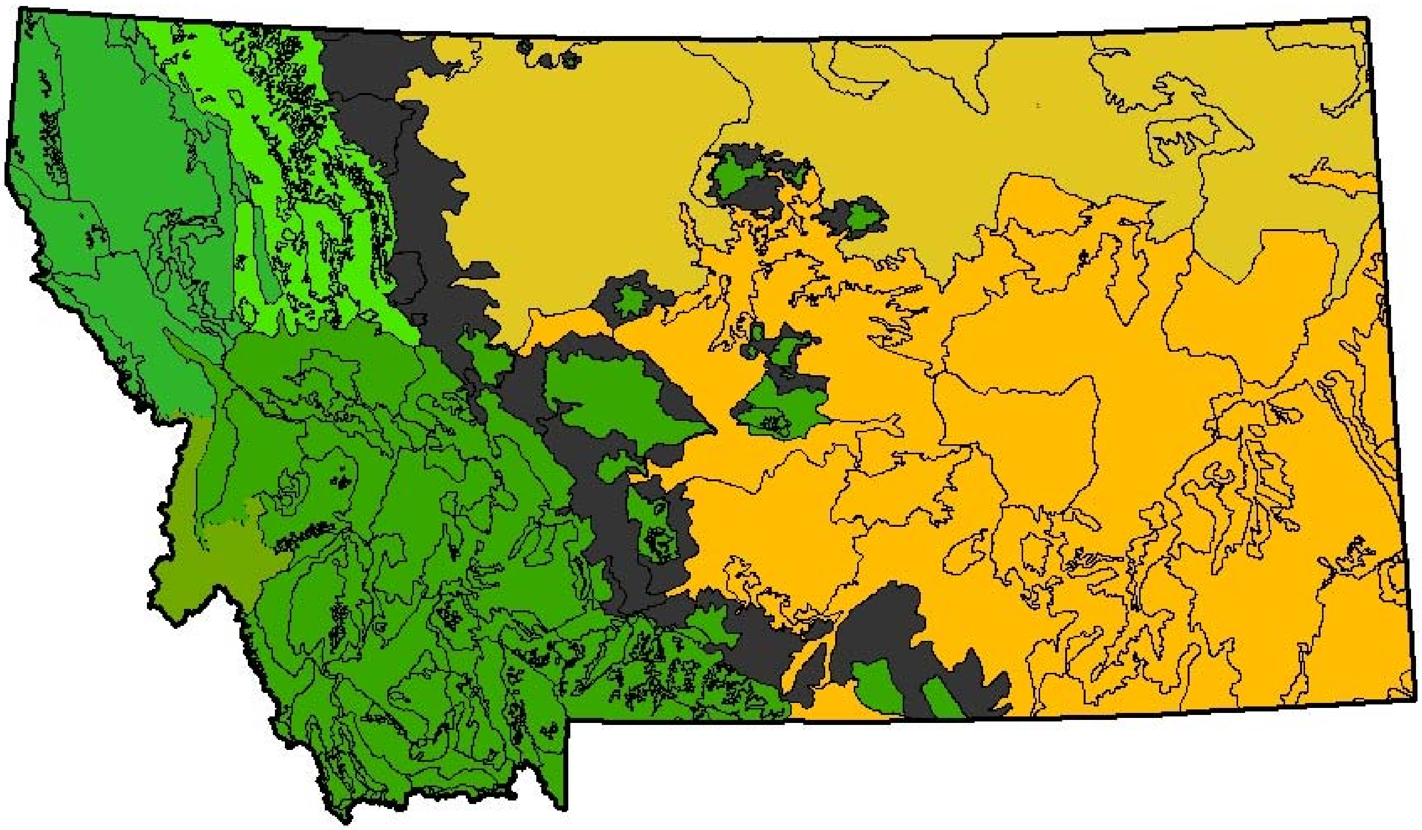
- In temperate streams worldwide that manifest a wide range of eutrophication, more than 90% of the streams have an average benthic algal Chl a < 150 mg/m^2

Gravel bottom wadeable streams of (mainly) western Montana

Areas where benthic algae sampling would be used in conjunction with nutrient samples

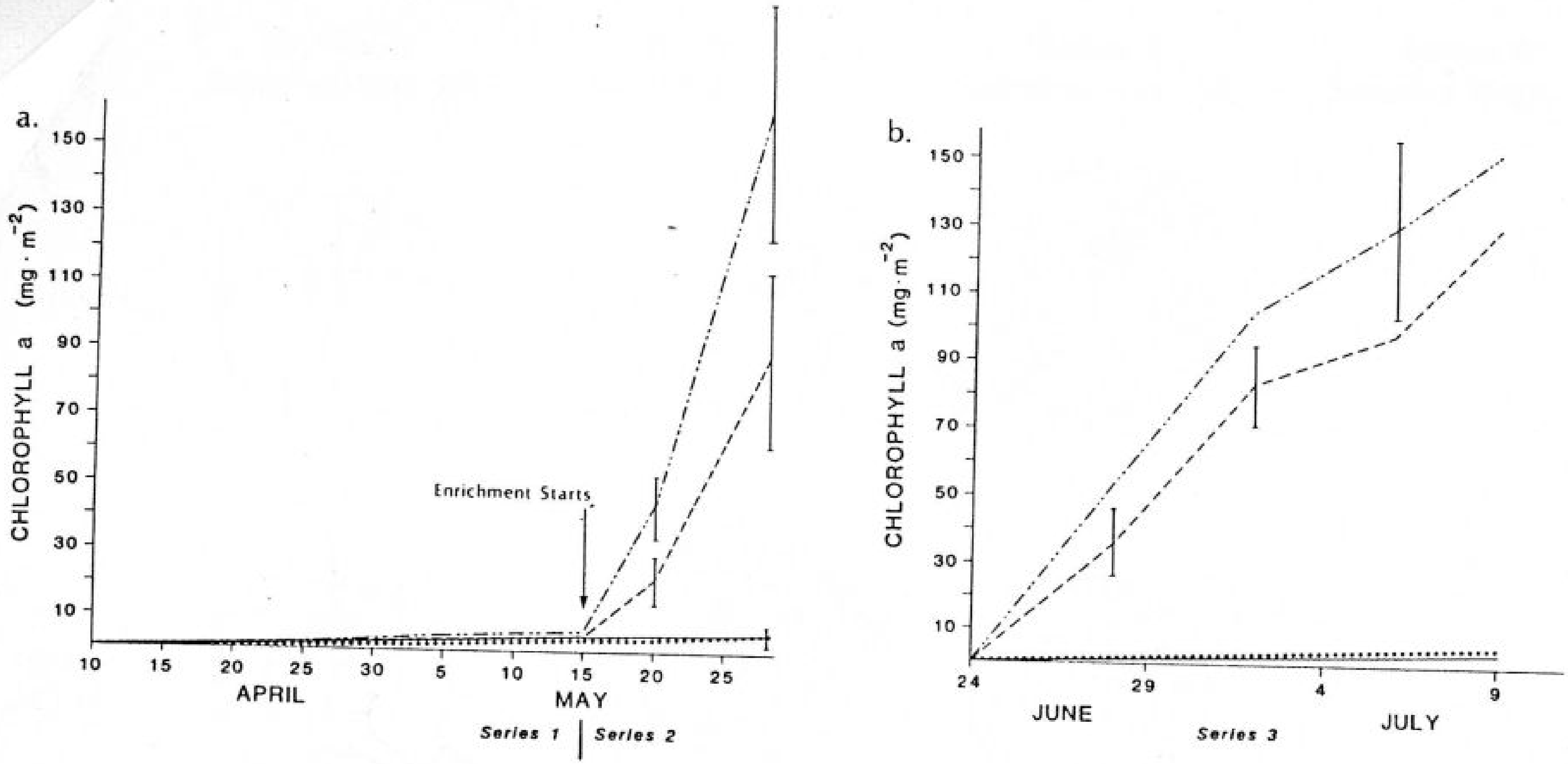


Areas where benthic algae sampling would be used in conjunction with nutrient samples



Biological changes: Findings from a regional whole-stream enrichment study (example)

High dose (dash-dot line): 0.025 mg SRP/L & 0.480 mg DIN/L



Perrin, C.J., Bothwell, M.L., and P.A. Slaney, 1987. Experimental enrichment of a coastal stream in British Columbia: Effects of organic and inorganic additions on autotrophic periphyton production. Can. J. Fish. Aquat. Sci. 44: 1247-1256.

Changes occurring from 0 to 150 mg Chl*a*/m^2

- Compared to unfertilized reach:
  - 1.5 orders-of-magnitude increase in algae density
  - By early July, filamentous algae (*Ulothrix*) was abundant in the fertilized reach, turning the stream a vivid green color
    - Increasing dominance by filamentous forms usually noted in similar studies
  - Juvenile salmon weights increased by up to 80% in the fertilized reach

Changes occurring when algae > 150 mg Chl *a*/m^2

- Loss of drifting stoneflies and mayflies and their replacement by chironomids and algal piercing caddisflies (which occur less in the drift than mayflies and stoneflies) would be expected to reduce feeding efficiency of larger, drift feeding fish such as adult trout (Quinn and Hickey, 1990)

- Nitrogen and benthic algal biomass *key* drivers affecting macroinvertebrate populations (Quinn and Hickey 1990)
  - Algae biomass negatively correlated to macroinvertebrate populations
  - Streams with elevated benthic algae (up to 283 mg Chl*a*/m^2) had lowered taxa richness and domination by Chironomidae (midges), Oligochaeta (worms), and Mollusca (snails)

- Simple models show that benthic algae need to be below 120 mg Chl *a*/m^2 (filamentous) to prevent DO from dropping below 5 mg/L when temp = 21^o C (Quinn and McFarlane, 1989)
  - @ 15^o C, ~ 200 mg Chla/m^2

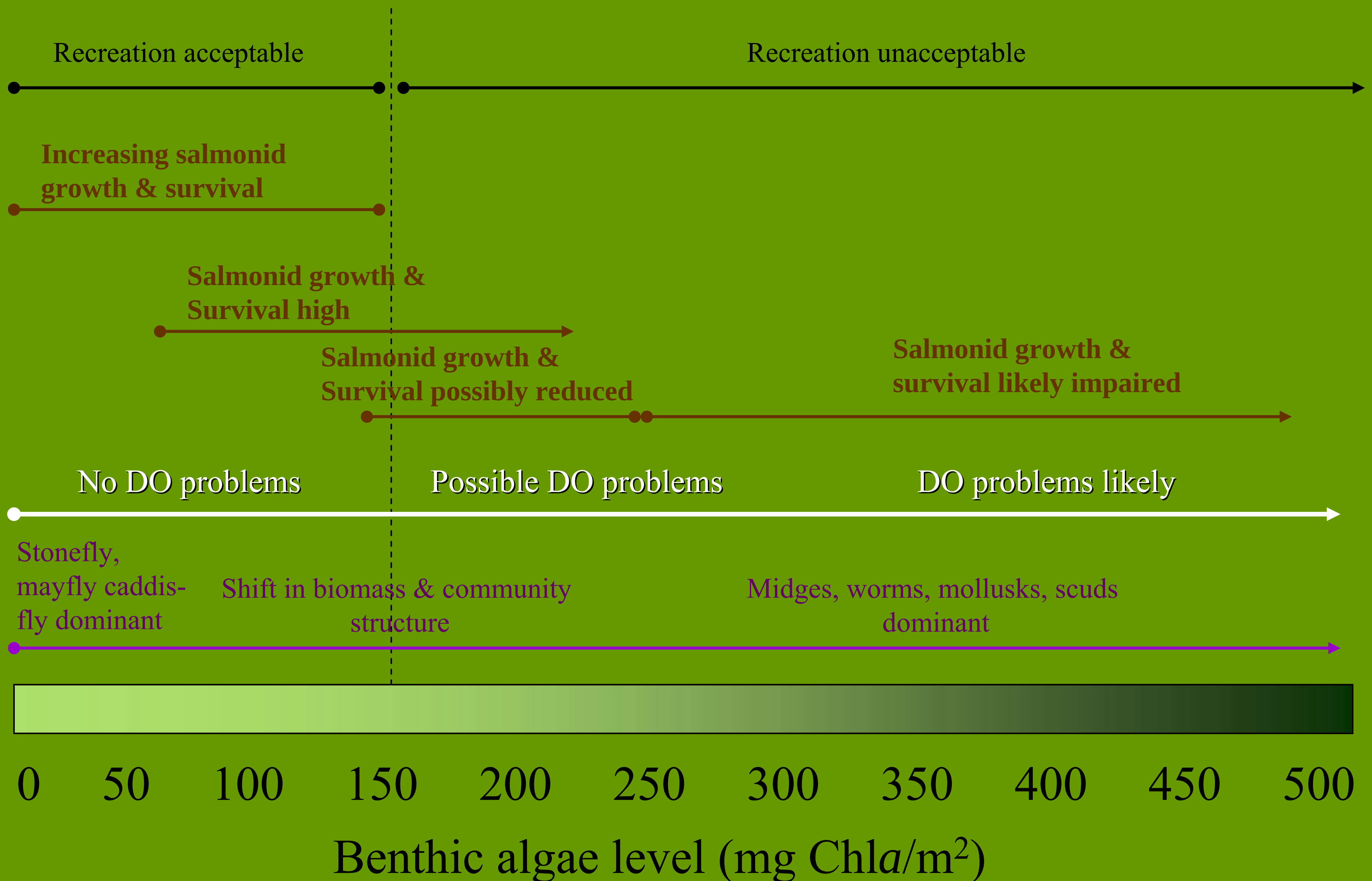
- New Zealand Ministry for the Environment recommends ~200 mg Chl *a*/m^2 (diatoms) or 120 mg Chl *a*/m^2 (filamentous) benthic algae limit to protect trout habitat

Biggs, B.J.F., 2000. New Zealand Periphyton Guideline: Detecting, Monitoring and Managing Enrichment of Streams. Prepared for Ministry of the Environment, June 2000

Roche Jaune FAS (Yellowstone River, near Miles City). 8/17/06; 12:05 pm

Distance From Shore	Site Depth	Temperature (^{o}C)	DO (mg/L)	DO (% SAT)	Saturation	Notes
27 m	29 cm	22.1	4.5	56	[DO SAT = 8.0 mg/L]	Bottom, in *Cladophora* beds
27 m	0 cm	22.1	7.7	96	[DO SAT = 8.0 mg/L]	Above *Cladophora* beds
37 m	32 cm	22.2	4.6	58	[DO SAT = 8.0 mg/L]	Bottom, in *Cladophora* beds
37 m	0 cm	22.2	7.3	91	[DO SAT = 8.0 mg/L]	Above *Cladophora* beds

Actual or likely affects on stream uses at varying algae levels



Key Points Summary

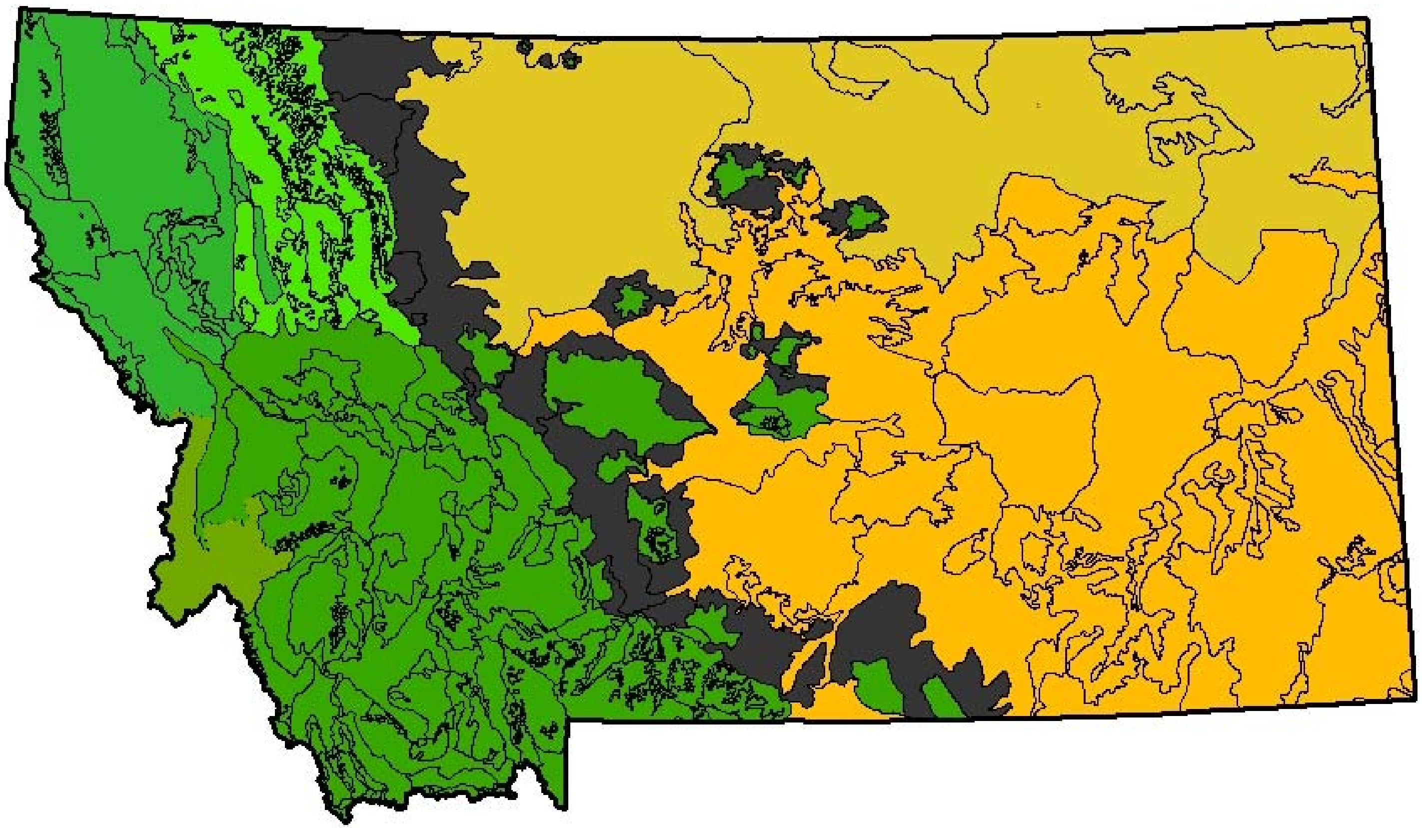
- Regional whole-stream fertilization study, which added nutrients at approximately DEQ's draft criteria, resulted in mean benthic algae of 150 mg Chl *a*/m^2, compared to 5 mg Chl *a*/m^2 in the control

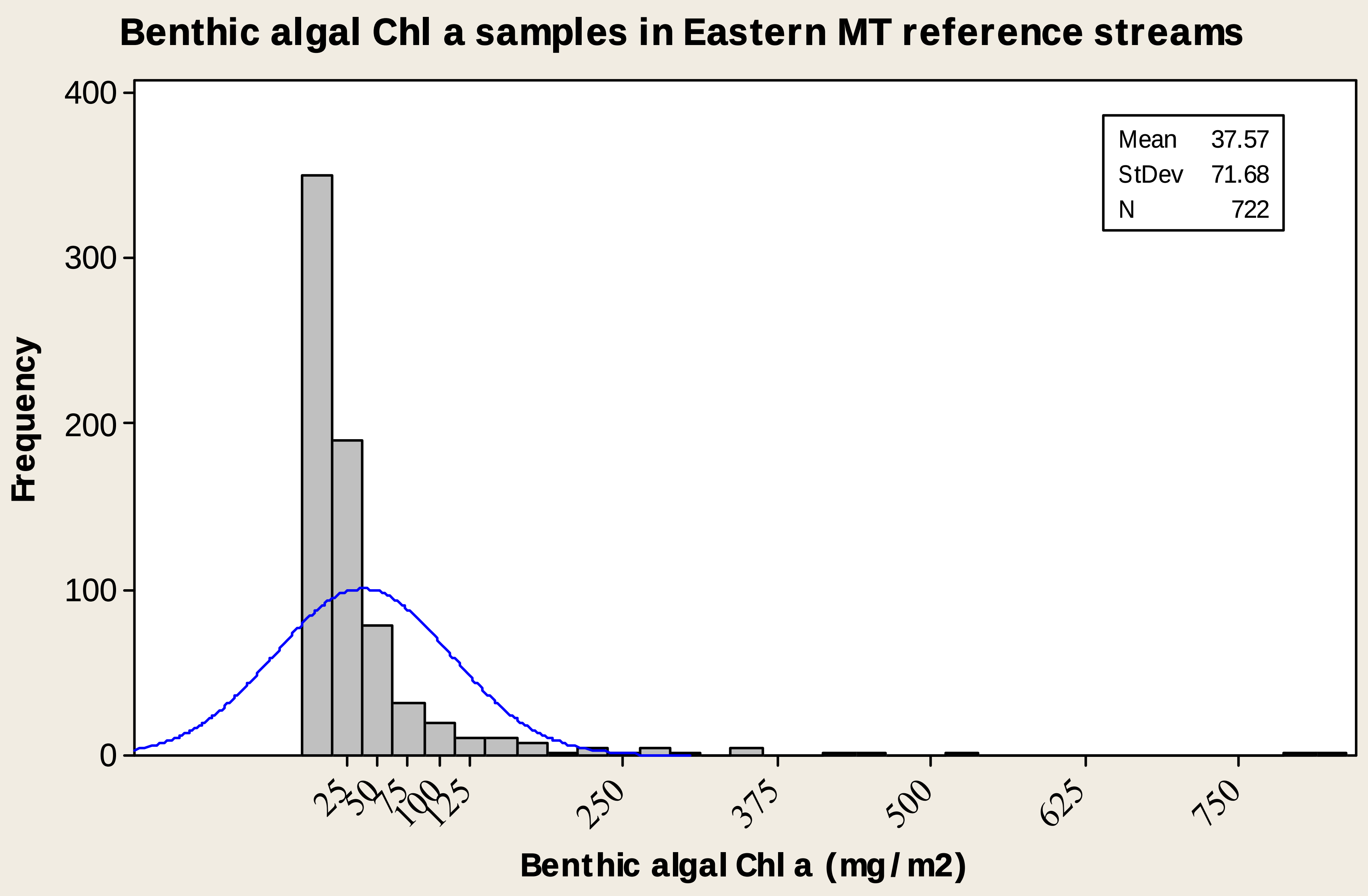
- Salmonid growth & survival is enhanced by increased nutrients and algal production, but further increases in nutrients leads to fishery impairment

- Risk of DO problems, salmonid fishery impairment, and significant alterations in macroinvertebrate communities increases when algae > 150 mg Chl *a*/m^2

Wadeable prairie streams of eastern Montana

Areas where benthic algae sampling would be used in conjunction with nutrient samples

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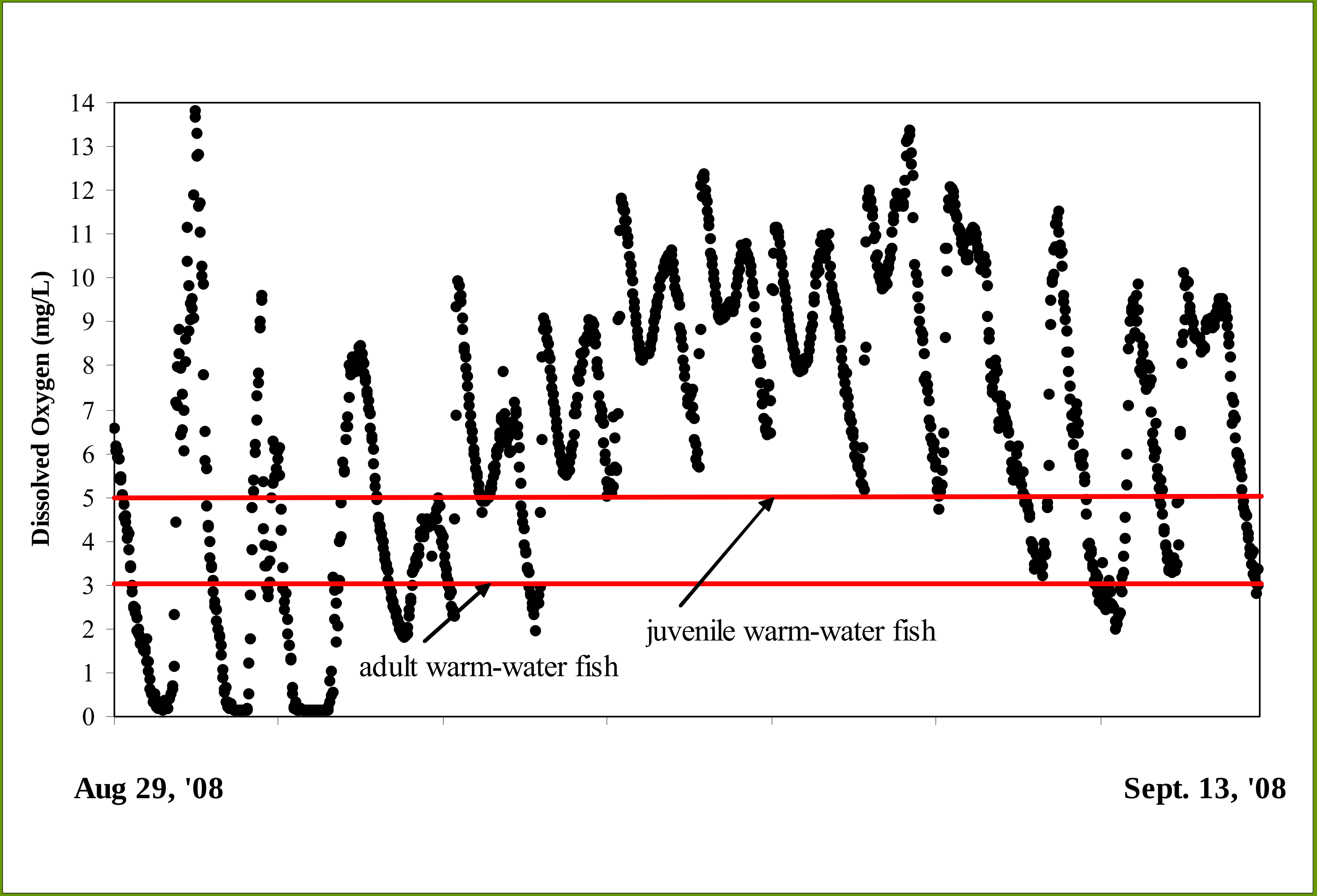
Benthic algal Chl a (mg/m2)

Harm-to-Use: Aquatic Life Thresholds



In eastern MT prairie streams, nutrient criteria are being set to maintain dissolved oxygen levels at state standards (fish, aquatic life)

Harm-to-Use: Aquatic Life Thresholds

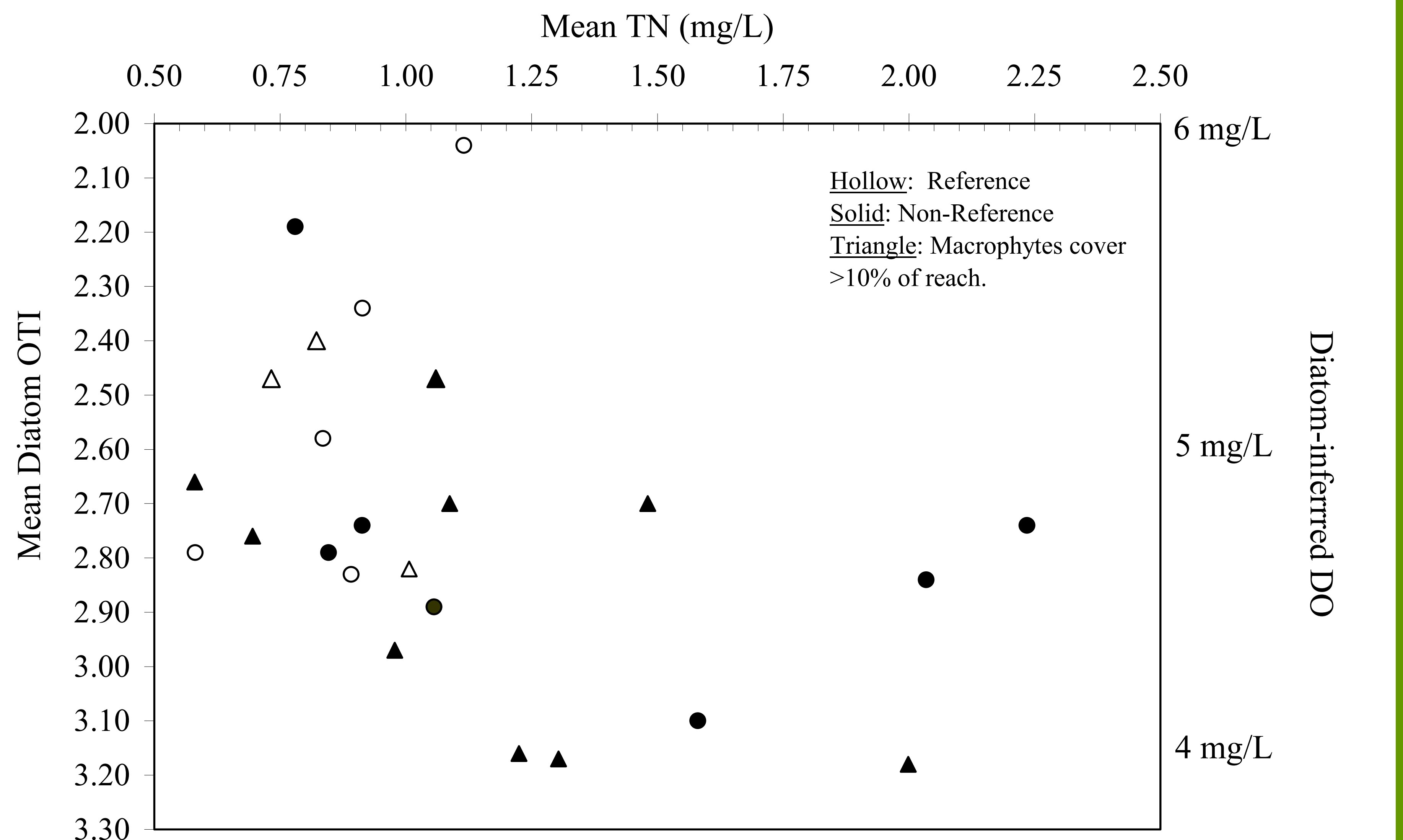


Figure 3.1. Scatterplot of Diatom OTI *vs*. Total N Concentrations, All Sites. Diatom-inferred dissolved oxygen (DO) was calculated based on a DO at saturation of 8 mg/L.

Key Points Summary

- Since benthic algae levels ≥150 mg Chl *a*/m^2 are more common in prairie streams, and these streams are physically very different than gravel-bottom trout streams, this algae threshold was not considered an appropriate harm threshold for prairie streams

- DEQ has shown a linkage between dissolved oxygen (DO) levels and nutrients in prairie streams, therefore the nutrient criteria are currently being set to maintain state DO standards

Criterion identification process

Criterion identification process

1. Collate all ecoregionally relevant stressor-response studies, set algae level in applicable equations to 150 mg Chl *a*/m^2
   - In E. MT prairie streams, use DO criteria to set threshold
2. Note where the nutrient concentrations from 1 above fall within their applicable reference distributions
   - For all stress-response studies, ~ 90^{th} of reference
3. Set criteria at 90^{th} of reference accept where other data support higher or lower concentrations
   - In Canadian Rockies, ~95^{th} percentile better value
   - In prairie streams 75^{th} best value at this time

Linking Stressor-response Studies & Reference Data

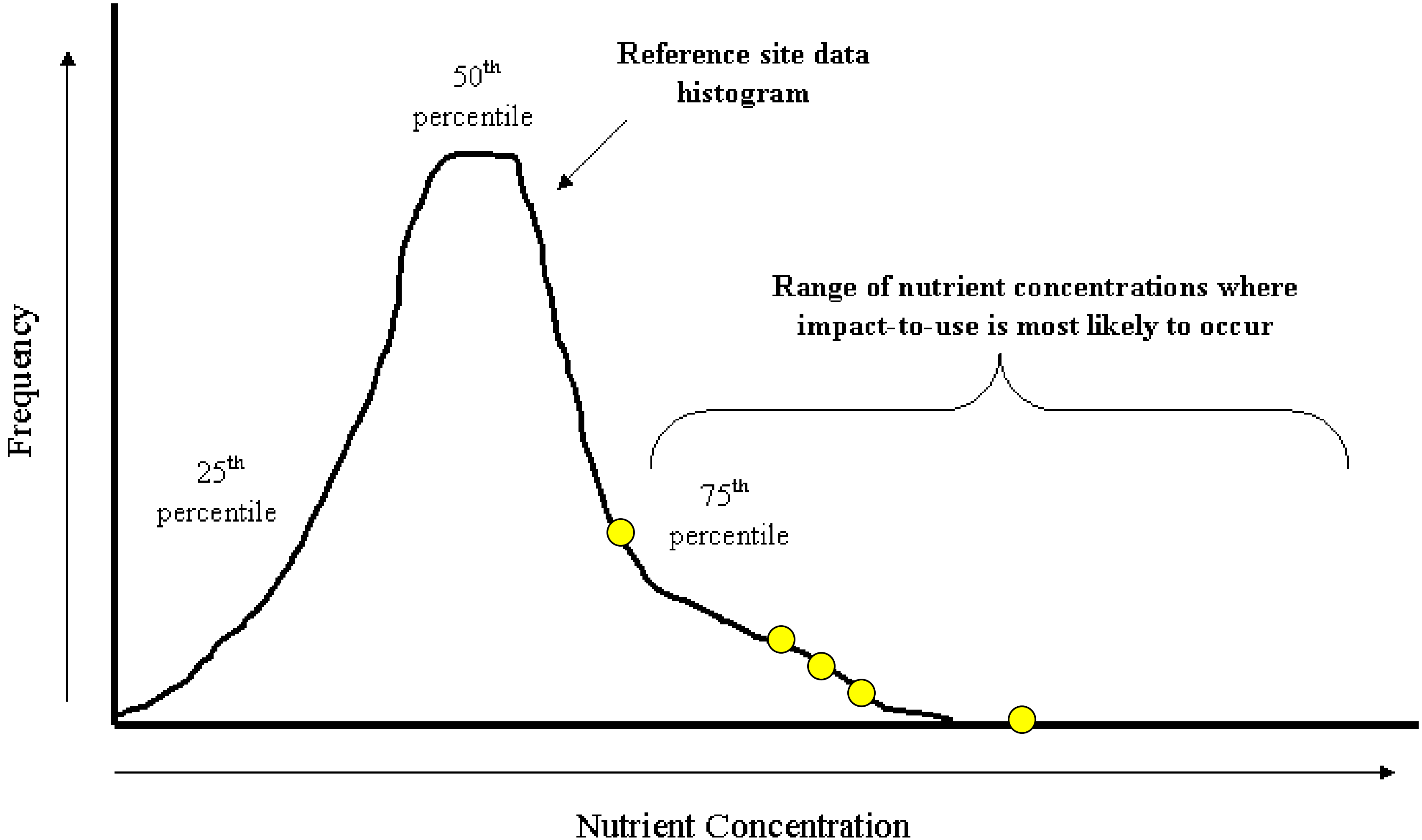


Figure 6.2. Conceptual Diagram Showing a Nutrient Concentration Histogram for Reference Sites. The figure shows where along the x-axis, relative to the histogram, nutrient concentrations likely to impact beneficial water uses would be expected to be found.

Linking Stressor-response Studies & Reference Data

Stressor-response Study	Nutrient	Stressor-response Study Nutrient Concentration (mg/L)	Season of Application	**Level III Ecoregion**	# Samples in During Summer Growing Season	**Percentile in Reference Distribution Matching Stressor-response Study Concentration**	Sensitive Benefical Use Nutrient Concentration Applies To:
			Reference Stream Sites				
Welch *et al*. (1989)	SRP	0.01	Growing (summer)	**Northern Rockies**	75	**94th**	Recreation
Watson *et al*. (1990)	SRP	0.011	Growing (summer)	**Middle Rockies**	211	**87th**	Recreation
Sosiak, A. (2002)	TP	0.018	Growing (summer)	**Canadian Rockies**	68	**97th**	Recreation
Bowman *et al*. (2007)	SRP	0.009	Growing (summer)	**Canadian Rockies**	59	**108th***	Recreation
Suplee *et al*. (2008) Technical Document (Appendix A)	TN	1.12	Growing (summer)	**Northwestern Glaciated Plains**	59	**70th**	Fish & Aquatic Life
					Mean:	**91**	
					Median:	**94**	
					CV (%):	**15**	

* Interpolated from dataset.

Also see Suplee, M.W., Varghese, A., and J. Cleland, 2007. Developing Nutrient Criteria for Streams: An Evaluation of the Frequency Distribution Method. *Journal of the American Water Resources Association* 43: 453-472.

Convert algae density to nutrient concentration, derive criteria

1) <u>$\ln$ Chl a (μg/cm^2) = 1.042 · $\ln$ SRP (μg/L) + 0.433</u>
   - Solve for 150 mg Chl$a$/m^2 (150 mg Chl$a$/m^2 = 15 μg Chl$a$/cm^2)

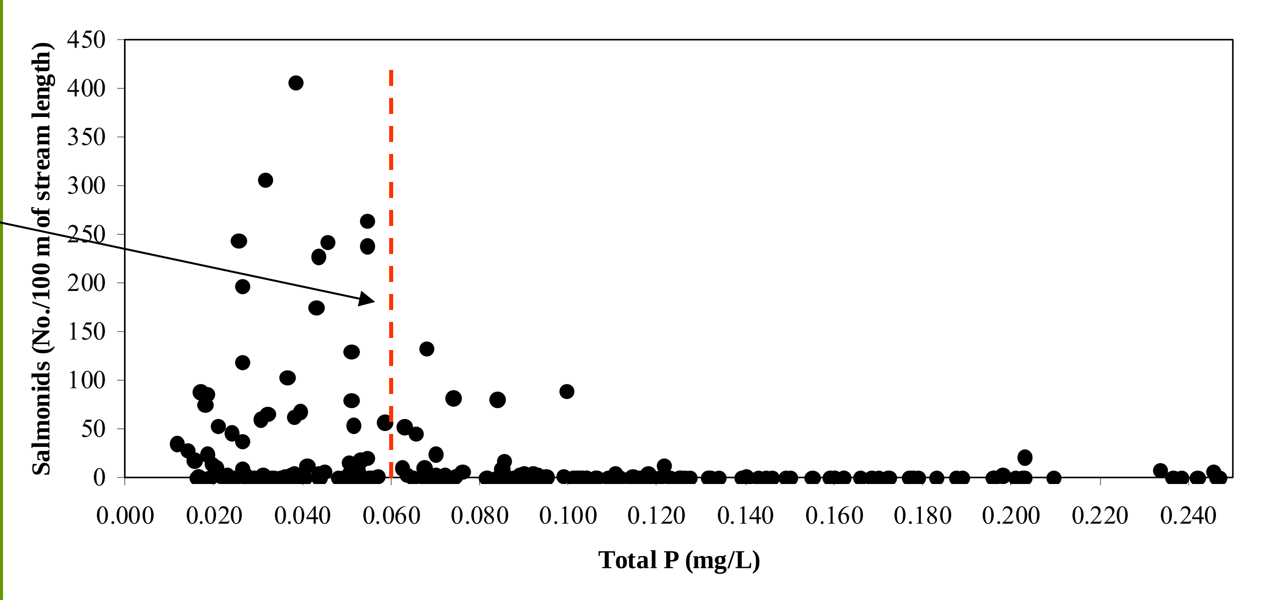
2) 150 mg Chl a/m^2 = 8.9 μg SRP/L (or 0.009 mg SRP/L)

3) Compare 0.009 mg SRP/L to SRP dataset collected from Canadian Rockies ecoregion reference streams
   - In this case, beyond the reference distribution; interpolated value = 108th percentile

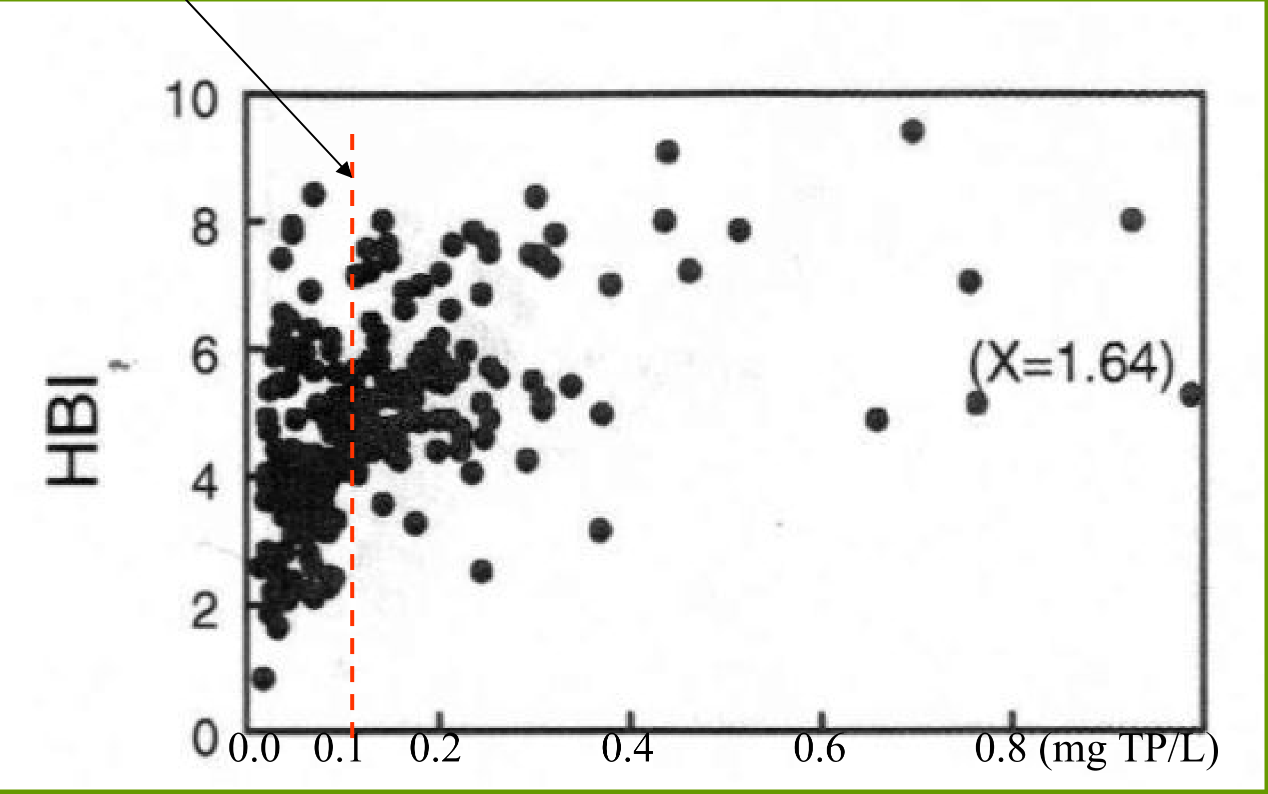
4) Consider overall relationship of stress-response studies to corresponding reference datasets
   1) Overall, 90th for state, ~ 95th percentile for W. MT
   2) Consider other factors, like balancing Redfield ratio to alternate nutrient, other regional studies, and scientific literature

5) Derive criterion for ecoregion

Salmonids changepoint: 0.06 mg/L



Macroinvertebrate biometric changepoint: 0.09 mg TP/L



Large study from Wisconsin streams shows harm-to-use nutrient concentrations in the same order-of-magnitude as Montana (Wang *et al*. 2007)

Summary

- 150 mg Chl*a*/m^2 is:
  - Considered a nuisance threshold by MT public
  - Rarely occurs in samples from western MT reference streams
  - Occurs in only the upper ~10% of temperate streams word-wide (Dodds *et al*. 2002)
  - DEQ used this value as a harm-to-use threshold for salmonid streams

- 150 mg Chl*a*/m^2 more common in prairie reference streams, and prairie stream ecology very different; therefore it has not been used as a harm-to-use threshold (i.e., it may be a natural characteristic of these stream types)
    - Using linkage to DO standards to derive criteria for prairie streams

- Salmonid growth & survival enhanced by increased productivity up to ~ 150 mg Chl *a*/m^2; beyond this algae level:
  - Increasing likelihood of salmonid impairment (but relationship is noisy)
  - DO problems can begin to occur at higher algae levels
  - Major changes in macroinvertebrate community function and structure

- Criteria derivation involves examination of regionally-applicable stressor response studies, linkage to reference data to help overcome uncertainty inherent to each stressor-response study

- Studies from other northern temperate regions generally result in same order-of-magnitude nutrient concentrations that protect uses